[PROC. ROY. SOC. VICTORIA 34 (N.S.), PT. II., 1922].

ART. XVIII.—*On the Changes of Volume in a Mixture of Dry Seeds and Water.*

BY ALFRED J. EWART, D.Sc., Ph.D. F.R.S.
(Professor of Botany and Plant Physiology in the University of Melbourne).

[Read 8th December, 1921].

If a quantity of dry peas is placed in a bottle filled with water, and provided with an open upright tube, it will be noticed that as the seeds swell the level of water in the tube rises, indicating a total increase of volume, and that after several hours the level of liquid in the tube falls again. The following observations illustrate this: The bottle used had a capacity of 1050 c.c., and 10 cms. of the erect tube contained 2.4 c.c. Peas were dried at 80°C., and the bottle two-thirds filled with them, and then filled up with water. The temperature of the peas was 20°C., and of the water 13.6. The increase or decrease of volume was measured from the height of liquid in the tube. The total

Temperature.	Time.	Total Increase or Decrease of Volume.
16·3°C.	12 a.m.	0·0c.c.
—	12.30 p.m.	+0·36 c.c.
16·3°C.	3 p.m.	+5·6c.c.
16·4°C.	3.50 p.m.	0·0c.c.
15·8°C.	10 p.m.	−18·7c.c.
13·8°C.	10 a.m.	−10·8c.c.

volume therefore first increases, then decreases by a still greater amount, and finally increases again. The final increase is apparent only, and is due to the production of small bubbles of gas by anaerobic respiration. It begins, however, before the bubbles actually appear.

This simple observation has long been known, and has been variously explained. It has even been stated to be a good way of demonstrating the expansion of seeds in water, ignoring the fact that the expansion of the seeds should be proportional to the amount of water they absorb, leaving the total volume unaltered.

The variation in the total volume might in fact be due to a variety of causes, and since seeds have specific structure, it need not follow the same course for all seeds. In regard to the first increase of total volume, this might be the result of the slight rise of temperature when dry seeds absorb water. Hence the experiment was repeated with the peas and water at the same original temperature (13.6°C.), the mixture being well stirred to remove any adhering air bubbles.

Temperature.		Time.		Total Increase or Decrease of Volume.
13·7°C.	-	10 a.m.	-	0·0c.c.
14·3°C.	-	12.10 p.m.	-	+6·9c.c.
14·8°C.	-	3.20 p.m.	-	+3·9c.c.

In this case a pronounced contraction of volume took place, while the temperature was still rising. The fact that the alterations of volume are far greater than any fluctuations due to changes of temperature can also be shown by direct estimation.

Using a bottle of 1050 c.c. capacity, with a tube attached, of which 10 cms.=2.4 c.c., the actual expansion of the water can be calculated from the formula—

$$v_t = v_0(1 + at)$$

where $a = 15 \times 10^{-6}$ between 10°C. and 20°C.

The increases of volume per 1°C. at various temperatures are given.

			Estimated Increase of Volume.		Observed Rise in Tube.
Between	10–12°C.	-	0·1056c.c.=0·44cms.	-	
	12–14°C.	-	0·1416c.c.=0·59cms.		
	14–16°C.	-	0·1512c.c.=0·63cms.	-	0·68cms.
	16–18°C.	-	0·1824c.c.=0·76cms.	-	} 0·82cms.
	18–20°C.	-	0·1920c.c.=0·80cms.	-	

In spite of the fact that the observed rise only gives the apparent expansion, it is greater than the theoretically calculated absolute expansion, but the methods used were not very refined, and were merely intended to show that the fluctuations of volume due to slight changes of temperature are small compared with those caused by the swelling seeds.

The increase of total volume with swelling peas is most pronounced when the seed coat has become markedly wrinkled, suggesting that the increase of volume is connected with wrinkling of the seed coat. This is easily proved by using split peas, in which case the total volume does not undergo any preliminary increase, but decreases from the outset until the final rise due to the production of gas. The first experiment was carried out with air-dry material, the second with material oven-dried at 80°C. The original total volume was 1050 c.c., and the receiver was two-thirds filled with the split peas. It will be seen that the contraction is much less with the air-dry material which already contained 16 per cent. of water.

Air Dry Split Peas.

Temperature.	Time.	Total Increase or Decrease of Volume.
11°C.	10 a.m.	0·0c.c.
11·5°C.	12.30 p.m.	−1·5c.c.
12·1°C.	11.30 p.m.	+0·77c.c.
	Oven Dried Split Peas.	
13·7°C.	11 a.m.	0·0c.c.
15·6°C.	1 p.m.	−6·1c.c.
13·3°C.	10.30 p.m.	+0·53c.c.

Similar results were obtained with split lentils, the material being first washed with spirit, and then rapidly with water to remove adherent air bubbles.

Split Lentils Air Dried.

Temperature.	Time.	Total Increase or Decrease of Volume.
13·3°C.	10.50 a.m.	0·0c.c.
13·8°C.	2.30 p.m.	−3·55c.c.
14·3°C.	6 p.m.	−3·15c.c.
	Split Lentils Dried at 80° C.	
13·4°C.	11.55 a.m.	0·0c.c.
13·4°C.	7.40 p.m.	−6·5c.c.
13·3°C.	5 a.m.	−5·66c.c.

The observations were discontinued as soon as a distinct increase of volume begins, for this is merely due to the appearance of gas bubbles, and proceeds rapidly once it has commenced.

Since the first increase of total volume shown with whole peas is due to the wrinkling of the seed coat, the suggestion may be made that the wrinkles are due to local regions of the skin absorbing water, and expanding more rapidly than others. This would result in a tendency to a partial vacuum beneath each wrinkle, and this would hasten the drawing in of water, and at the same time increase the total volume of the mixture of seeds and water. If this were so, then under pressure the first expansion should be either greatly decreased or suppressed.

For this purpose a stout separating funnel was used. Peas and water were introduced at the top, which was then sealed. To the lower end a long-armed U tube was attached. This contained a water column continuous with that in the funnel. Mercury was then poured into the open arm of the U tube until the difference of level was 76 cms. After each reading the mercury was brought up to the original level if contraction had taken place, or reduced to the same level with the aid of a pipette if expansion had occurred. The temperature varied within 1°C. during the experiment, a maximum rise of 1°C. being shown after three hours, when the total volume had begun to decrease. The total initial volume was 1080 c.c. and a two-thirds charge of oven-dried peas was used.

Time.	Total Increase or Decrease of Volume.	
3 p.m.	[0·0c.c.]	0·0c.c.
3.35 p.m.	[+2·3c.c.]	−0·10c.c.
4 p.m.	[+4·7c.c.]	+0·28c.c.*
4.40 p.m.	[+6·3c.c.]	+0·76c.c.
5 p.m.	[+2·1c.c.]	0·0c.c.
8 p.m.	[−2·4c.c.]	−2·0c.c.
9 p.m.	[−3·0c.c.]	−4·8c.c.
9 a.m.	[−1·1c.c.]*	−5·6c.c.†
10 a.m.	—	−5·6c.c.

* Seeds beginning to wrinkle.
† Seeds fully swollen.

Owing to the pressure the final expansion due to the liberation of gas bubbles is long delayed. The figures in brackets give the expansion and contractions of a similar volume of peas and water not under pressure. At * gas production began preventing the full contraction of volume.

It will be noticed that under pressure there is a slight contraction of volume before the expansion due to the wrinkling of the seed coat begins. This is probably the result of the pressure on air in the intercellular spaces of the cotyledons. These are not entirely obliterated on drying, as can be seen by examining sections of dry peas in pure glycerine. A large receiver with a manometer attached showed an unchanged pressure of –76 cms. for an hour after exhaustion with a double Geryck pump. It was then filled with dry peas, and again rapidly exhausted. The exhaustion required a few more strokes, and on standing for an hour the pressure increased from –76 cms. to –72 cms., then remaining stationary. This shows that the dry peas do actually contain a little air.

In the case of all seeds in which the seed coat wrinkles more or less during absorption, the total volume shows a preliminary increase, followed by a decrease, as in the case of peas, and a final increase of volume, which is only apparent, and is due to the production of gas. It usually begins before any actual gas appears, but is then due to gas forming in the intercellular spaces of the seed, and driving out some of the water contained in them.

Tick (Horse) Beans. Total Volume 1065 cc. ⅔ Charge of Beans.

Temperature.	Time.	Total Increase or Decrease of Volume.
11·4°C.	10.40 a.m.	0·0c.c.
12·2°C.	5 p.m.	+9·98c.c.
12·5°C.	7.30 p.m.	+9·28c.c.
11·7°C.	10.15 a.m.	–2·54c.c.
12·0°C.	10 p.m.	–4·39c.c.
11·6°C.	10 a.m.	+2·5c.c.

Haricot Beans. Total Volume 1055 cc. ⅔ Charge of Beans.

Temperature.	Time.	Total Increase or Decrease of Volume.
12·5°C.	3 p.m.	0·0c.c.
12·65°C.	3.40 p.m.	+2·5c.c.
13·3°C.	7.45 p.m.	–4·6c.c.
11·8°C.	10 a.m.	–10·08c.c.
12·6°C.	5.15 p.m.	–14·6c.c.
12·6°C.	7 p.m.	–11·2c.c.*

* No bubbles of gas as yet formed.

In the case of barley and cereal grains in which the integuments do not wrinkle while absorbing water, the total volume contracts from the commencement until the rise due to gas production begins.

The following tests give the contractions obtained with air-dried and oven-dried barley. The total volume was 1056 and

1060 c.c. respectively. The receiver was two-thirds filled with barley, after this had been rapidly washed with spirit to remove air, and with water to remove light grain.

BARLEY (AIR DRIED).

Temperature.	Time.	Total Contraction.
13·8°C.	zero	0·0c.c.
13·5°C.	24 hours	—2·38c.c.
	BARLEY (OVEN DRIED).	
12·4°C.	zero	0·0c.c.
12·4°C.	6 hours	—3·02c.c.

It is of interest to compare these contractions with those of agar and gelatine when swelling in water. Ordinary flake or strip agar or leaf gelatine cannot be used, as it is impossible to obtain a mixture with water free from air, and they swell too rapidly. Nelson's strip gelatine gave good results, and granulated agar was used, the granules swelling to the size of kidney beans or broad beans in water. In both cases a rise of temperature of 0.5 to 1°C. takes place, but the final readings were taken when the temperature had fallen approximately to the calorimeter level again. The contraction of volume is small, and it takes place almost wholly in the first hour with the gelatine, and in the first seven hours with the agar, i.e., long before either are fully swollen.

GELATINE. 150 GRAMS. TOTAL VOLUME, 1050 CC.

Temperature.	Time.	Contraction of Volume.
15·5°C.	zero	0·0c.c.
15·5°C.	70 minutes	0·912c.c.
AGAR. 50 GRAMS.	TOTAL VOLUME, 1056 CC.	
15·2°C.	zero	0·0c.c.
15·1°C.	7 hours	0·65c.c.

At a temperature of 15°C., 1000 c.c. of water would undergo a decrease of volume of 0.495 c.c. under an increased pressure of 10 atmospheres. Hence a decrease of 0.912 c.c. indicates an increased pressure of 20 atmospheres. This is exercised on the water by the gelatine in the process of swelling. The pressure is probably much greater than this at first, and lessens as the gelatine swells throughout, but on the other hand, more water is under compression. The maximal total contraction will be given at some intermediate point between commencing absorption and complete absorption and swelling.

There may be two reasons for the greater contraction of volume with swelling seeds as compared with the gelatine. Using equal volumes of barley, haricot beans and peas, the maximal contraction obtained varied from 2.5 to 6 c.c., but in all cases were greater than with gelatine. This would indicate absorption pressures of 50 to 120 atmospheres. An organised colloid, like cellulose, may be capable of showing a higher absorption pressure than an unorganised one like gelatine. In addition a certain amount of solution may take place in the seed as water is absorbed. Tamman[1] has shown that a volume of a solution under one atmosphere pressure expands when heated like a similar volume of water under a constantly higher pressure, i.e., a solution has a high internal pressure due to the solute. This action is a general one, independently of whether the solute is an electrolyte or a non-electrolyte. In other words, the minimum volume temperature of water is lowered by the presence of a solute. It follows, therefore, that as some of the food constituents of the seed begin to dissolve, the total volume may tend to undergo a slight decrease as the result of the action of the solute. There are, however, certain exceptions to this rule. For instance, a mixture of ammonium chloride and water expands on solution, so that a 6.85 per cent. solution has an increased volume of 0.266 c.c. (100.266 c.c. instead of 100 c.c.).[2] Hence it is impossible to say exactly what part may be played by dissolving solids in producing a contraction of the total volume.

In addition, if cellulose obtained from a colloidal solution has the same composition as that in the cell-wall, the fact that it has a higher density may indicate that in penetrating the cell-wall the water molecules may partly enter empty intermicellar spaces, thus producing a contraction of total volume. It is at least evident that the changes of volume in a mixture of dry seeds and water are by no means simple phenomena, but are due to various interacting, and in some cases antagonistic factors.

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1 G. Tamman, Ueber die Beziehungen Zwischen den inneren Kräften and Eigenshaften der Lösungen, Voss, Hamburg and Leipzig, 1907.

2 Happart, Bulletin Inst. Liege, 1903.

Summary.

Marked changes of the total volume are shown when dry seeds absorb water.

If the seed coat wrinkles, there is first an expansion, then a contraction, and then a final rise which is due to the production of gas in the seed. The changes are not the result of alterations of temperature. The wrinkling is due to unequally rapid absorption, partial vacuums forming under the wrinkles, which hasten the indrawal of water. If the seed coat does not wrinkle there is no preliminary expansion, and the contraction is due as in gelatine to the compression of the absorbed water.

Using similar methods as with the seeds, the contraction obtained with gelatine indicated a pressure of 20 atmospheres, but with seeds as much as 50 to 120 atmospheres pressure was indicated. This may be due partly to the greater imbibition pressure of organised cellulose as compared with gelatine, and partly to the influence of solutes increasing the internal pressure of the water within the seeds.